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Flexural and Post-cracking behavior of Geogrid-reinforced Concrete Beam for Pavement application

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ABSTRACT

Geosynthetics have been used as reinforcement and stabilization elements in the base and subbase layers of flexible pavements, as well as reinforcement inclusions in asphalt overlays, particularly mitigating rutting reflective cracks. Recently, the use of geogrids as reinforcement elements has expanded into Portland cement concrete (PCC) pavements as an alternative to steel reinforcements. Research conducted so far has indicated that the use of of geogrids as reinforcement in concrete pavements shows both post cracking ductility and superior load capacity. Although this topic is not yet so explored in the literature, the use of geogrids in concrete pavements, pathways, floating slabs or beams is promisor and gives a new employment area for the use of geogrid reinforcements. This paper presents an experimental investigation on the flexural behavior, post-cracking and fracture energy performance of geogrid-reinforced concrete beams under four-point bending test. Triaxial geogrids were embedded at one-third depth of concrete beam specimens (500 × 150 × 150 mm). The PCC mix was prepared using Type I Portland cement with compressive strength of 35 MPa. Results confirmed that the flexural performance and post-cracking resistance of the concrete beam specimens reinforced with triaxial geogrids can be improved, as evidenced by load-deflection response and crack mouth opening displacements. Triaxial geogrids showed 11% increase in flexural strength of concrete beam, highlighting the potential benefits of geogrids reinforcements in PCC pavements.

1. INTRODUCTION

Geosynthetics have been used as reinforcement and stabilization elements in the base and subbase layers of flexible pavements, as well as reinforcement inclusions in asphalt overlays, particularly mitigating rutting reflective cracks. Recently, the use of geogrids as reinforcement elements has expanded into PCC structures as an alternative to steel reinforcements due to its tensile strength and ductility. PCC structures are usualy reinforced with traditional steel mesh to provide the strength required to resist stresses caused by traffic loads, but there are still few limitations restraining their use, such as steel corrosion (Tang et al., 2008). Although this topic is not yet so explored in the literature, the use of geogrids in concrete pavements, pathways, floating slabs or beams is promisor and gives a new employment area for the use of geogrid reinforcements.

Research conducted so far has indicated that the use of of geogrids as reinforcement in concrete pavements shows both post cracking ductility and superior load capacity (Tang et al., 2008; El Meski and Chehab, 2014; Chidambaram and Agarwal, 2015; Itani et al., 2016; Chand Beebi and Visweswara Rao, 2017; Tang et al., 2018; Al-Hedad and Hadi, 2019; Meng et al. 2019). According to Tang et al. (2018), due to geogrids relatively high strength-to-weight ratio, ease of handling and relatively lower cost, they have been increasingly investigated for potential use as reinforcements for PCC. Al-Hedad and Hadi (2019) states that polymeric geogrid products have several structural advantages making them a potential alternative of steel reinforcement for PCC thin sections under relatively light loading conditions, including high tensile strength and excellent chemical resistance. Tang et al. (2018) states that, besides benefits evidenced by findings from the aforementioned studies, the effectiveness of a geogrid in reinforcing PCC is still not well understood, specially regarding geogrid engagement and mobilization in PCC slabs under flexural loading.

Tang et al. (2008) evaluated biaxial geogrids installed at one-third depth of concrete beam specimens (560 × 150 × 150) through third-point monotonic loading (rate of 1.2 mm/min). Results showed showed that geogrids added substantial post-cracking ductility and extended crack propagation after crack initiation and before concrete beam failure, while unreinforced beam failed in a brittle mode. El Meski and Chehab (2014) studied uniaxial, biaxial and triaxial geogrids installed at one-third depth of Type I Portland cement concrete beam specimens (530 × 150 × 150) under four-point bending test (rate of 0.12 mm/min). Results confirmed that all types of geogrid-reinforced concrete beams provided ductile post cracking behavior, high fracture energy, high flexural strength, and large deflection. Biaxial and triaxial geogrids behaviors were comparable in terms of increase in load capacity and reduction in deflection capacity compared. However, the improvement in postpeak behavior was more pronounced in biaxial than triaxial geogrid-reinforced beams. Tang et al. (2019) studied the potential benefits of embedding triaxial geogrids in concrete slabs using four-point bending tests. Load and midspan deflection data were recorded. Results showed that geogrid did not contributed to improve concrete the peak flexural strength, but carried additional load after crack initiation and were able to hold the reinforced concrete beam with macrocracks, suggesting concrete collapse failure delay.

The present study conducted an experimental investigation on the flexural behavior of geogrid-reinforced concrete beams under four-point bending test. Triaxial geogrids were embedded at one-third depth of concrete beam specimens to allow for comparison between unreinforced concrete beams. Post-cracking performance was also evaluated.

2. EXPERIMENTAL PROGRAM

2.1 Materials

The concrete mix used in this research was designed using Type I Portland cement, water/cement ratio of the mixtures of 0.44 and nominal maximum size of the coarse aggregates (9.5 mm), which is smaller than geogrid opening aperture, allowing interlocking. For 1.0 m³ of concrete, the weights of the cement, sand, aggregates were 514, 463, 726 kg, respectively. The concrete mixture was designed to product compressive strength of 40 MPa at 28 days, according to ASTM C 39. Superplasticizers were not used. The geogrid used in this research is a polypropylene triaxial type (three equilateral directions). Table 1 presents characteristics of the tested geogrid provided by the manufacturer.

Table 1. Characteristics of tested triaxial geogrid.

Characteristics	Longitudinal	Diagonal	Transverse	Specification
Index Properties				
Rib pitch (mm)	40	40	-	
Mid-Rib Depth (mm)		1.8	1.5	
Mid-Rib Width (mm)		1.1	1.3	
Structural Integrity				
Junction Efficiency (%)		93		ASTM D6637
Radial Stiffness at @ 0.5% strain (kN/m)		300		ASTM D6637
Durability				
Resistance to chemical degradation		100%		EPA 9090

2.2 Specimens preparation

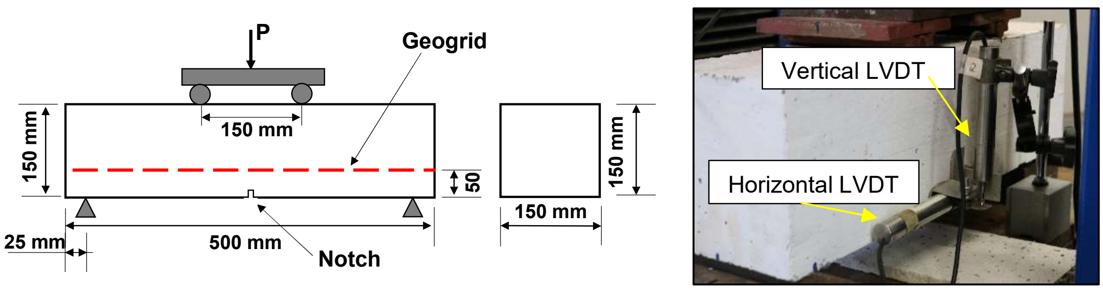
In order to evaluate flexural and post-cracking behavior of geogrid-reinforced concrete beams compared to unreinforced concrete beams, four-point flexural bending test was conducted. Wood molds were constructed with internal dimensions of 500 × 150 × 150 (mm). The geogrids (Figure 1a) were cut to fit wood mold area and its location was selected at one-third depth (50 mm) of concrete beam specimens (Figure 1b) in order to be within the tension zone. Concrete was cast in three successive layers with proper vibration using a vibrating table (Figure 1c). At least two replicates per specimen (reinforced and unreinforced type) were tested. Specimens were kept in an environmental chamber for 28 days before testing.

a) Triaxial geogrid b) Geogrid installation c) Finished concrete beam specimens

Figure 1. Geogrid and concrete beam specimens.

2.3 Flexural Loading Test Setup

Flexure tests were conducted using four-point bending tests under monotonic loading, following ASTM C78. Two different configurations were tested, represented by unreinforced (UR) and triaxial geogrid-reinforced (TX) concrete beams. The concrete beams were prepared in the laboratory and tested were conducted in a 60-ton servo-hydraulic universal testing machine, under displacement control ratio of 0.08 mm/min, until failure in flexure. A 10-mm deep and 4.5-mm wide notch was sawed across the center of the bottom surface of the beams in order to induce failure cracking. The configuration of notched concrete beams test setup is shown in Figure 2a. A vertical linear variable differential transformer (LVDT) was installed to measure midspan deflection during loading (Figure 2b), as well as a horizontal LVDT to measure crack mouth opening displacement (CMOD) of the notch. Data was acquired to capture post-cracking behavior.



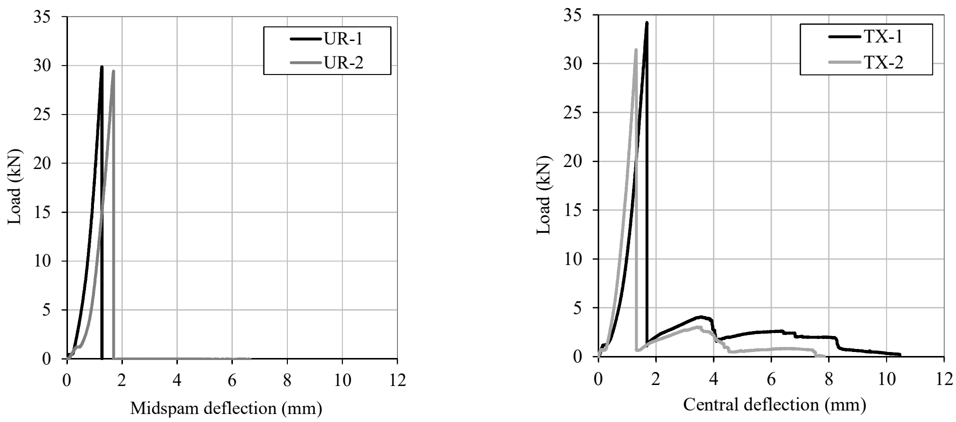
(a) Configuration of notched concrete beams (b) Instrumentation

Figure 2. Configuration of loading and instrumentation setup.

3. RESULTS AND ANALYSIS

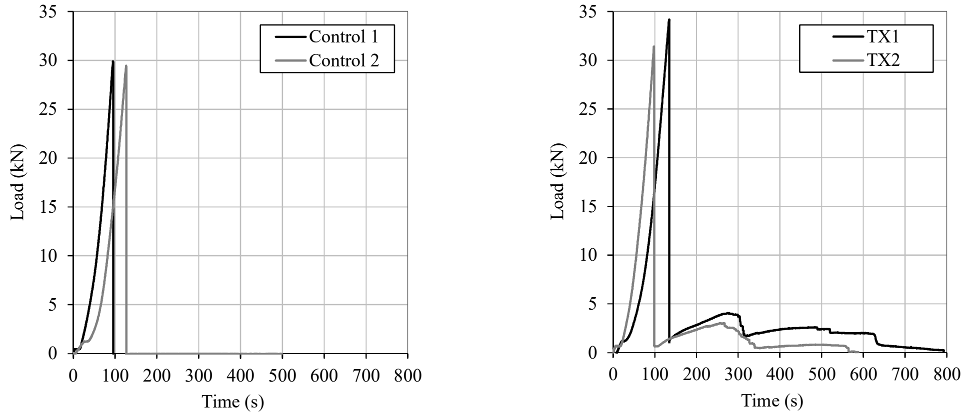
3.1 Load-deflection curves

The load-vertical displacement curves of reinforced and unreinforced concrete beams are presented in Figure 3. Figure 4 shows flexural load as function of time. Results of unreinforced concrete beams, where specimens failed in a brittle mode imediately after peak, reached peak loads of 30 kN at failure. On the other hand, the load-deformation curves of reinforced-concrete specimens exibited delayed failure and aproximately up to 14% extra peak load. The peak loads were followed by a load drop. At this point, cracks initiated at notch location and the load was then completely absorbed by the geogrids. After load drop, reinforced-geogrid beams gained post-cracking ductility until cracks reached top surface beams, where failure was completed. Results in Figure 3 shows excelent repeatibility of the replicate tests, as well as the increase in peak load of reinforced-concrete beams compared to unreinforced beams.



a) Unreinforced concrete beams b) Geogrid-reinforced concrete beams

Figure 3. Flexure test load versus midspam deflection patterns and failure modes.



a) Unreinforced concrete beams

b) Geogrid-reinforced concrete beams

Figure 4. Flexure load-time curves.

Figures 5 to 7 show the observed modes of failure of each case. Unreinforced concrete beams were immediately separated in two blocks each after failure (Figure 5). In both reinforced beams, it was possible to visualize that crack growth (Figures 6 and 7), were significantly slower cracks developed in comparison with plain concrete beams.

(a) UR-1

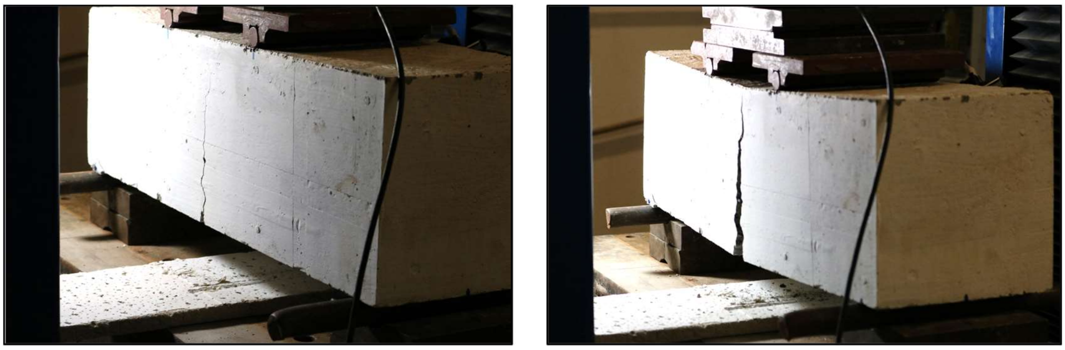
(b) UR-2

Figure 5. Immediate brittle failure of control specimens.

(a) Crack initiation and propagation

(b) failure mode in reinforced beam

Figure 6. Geogrid-reinforced concrete beam (TX-1) failure.



(a) Crack initiation and propagation (b) failure mode in reinforced beam

Figure 7. Geogrid-reinforced concrete beam (TX-2) failure.

Still in Figure 3, peak load of unreinforced beams occurred at maximum deflection of approximately 1.5 mm. In geogrid-reinforced concrete beams, peak load occurred at deflection of approximately 1.7 mm. This behavior reflects that geogrids did not contributed mechanically in the pre-cracking phase, as also observed by Masri et al. 2018. In the study of El Meski and Chehab (2014), triaxial reinforced beams also suffered a sudden failure similar to the unreinforced beams, which did not happen for biaxial or uniaxial geogrids. As observed by El Meski and Chehab (2014) and in the results of the present study, their main contribution of the triaxial geogrid in concrete beam was limited to providing post cracking ductility and some extra load capacity.

Table 2 presents a summary of flexural strength tests results. Another important aspect from the flexural strength analysis is the modulus of rupture (R) of the specimens, which is calculated from the following equation:

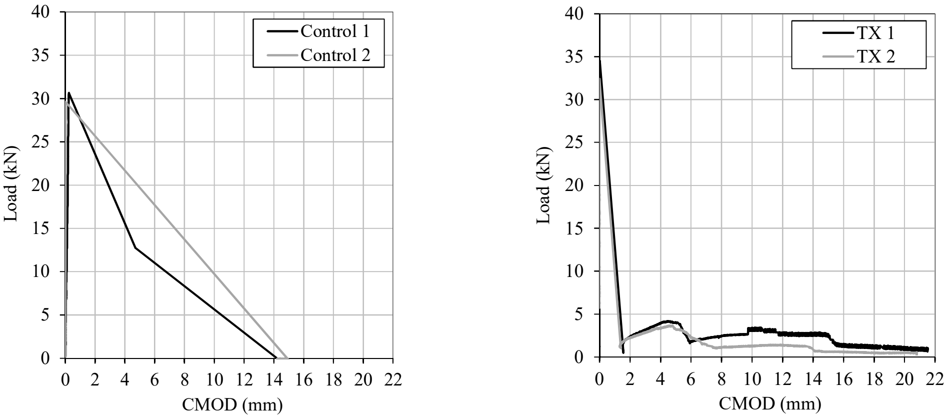
$$R = \frac{P.l}{b.d^2}$$

where P = the maximum total load measured (kN); l = span length of 45 cm; b = width of the specimen (150 mm); and d = height of the specimen (150 mm). According to results presented in Figure 3, modulus of rupture was calculated for unreinforced and geogrid-reinforced beams. Results showed that the presence of the triaxial geogrid provided an increase in flexural strength to the concrete beams by approximately 11%. Results of El Meski and Chehab (2014) showed increase in flexural strength of concrete beam of 6% for triaxial geogrids. On the other hand, in the studies of Tang et al. (2018) and Tang et al. (2019) biaxial geogrids did not exhibit benefits in improving flexural strength of simply-support concrete beams under four-point bending.

Table 2. Summary of flexural strength tests results.

Characteristics	P_{max} (kN)	Minimum load after cracking (kN)	Post cracking max. Load (kN)	Modulus of rupture (kPa)
UR-1	30	-		3987
UR-2	29	-	-	3840
TX-1	34	1.1	4.4	4560
TX-1	31	0.7	3.0	4160

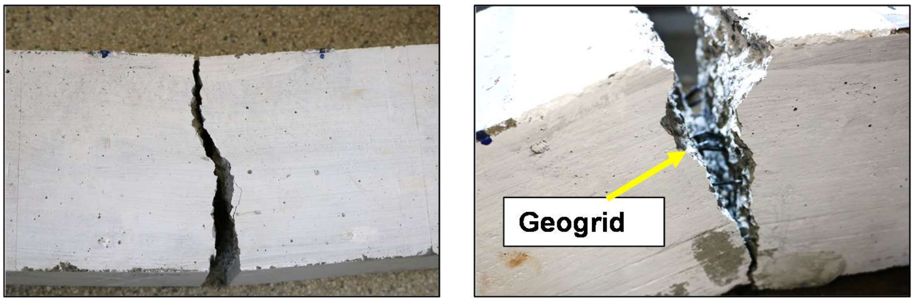
Crack mouth opening displacements (CMOD) at the notch of the beams were measured during flexural tests and are presented in Figure 9. Unreinforced beams showed abrupt drop of load, along with a significant increase of CMOD measurements. Geogrid-reinforced concrete beams showed also an abrupt drop of load, but after drop, load is redistributed to the geogrids and CMOD increases gradually as geogrid ribs elongate until gradual rupture. Figure 10 shows that triaxial geogrid ribs were stretched after crack opening, illustrating the gradual rupture behavior observed in Figure 9b, in which multiple post peaks loads were registered. According to observations after the tests, geogrid failure was more on ribs than on junction.



a) Unreinforced concrete beams

b) Geogrid-reinforced concrete beams

Figure 9. Flexure load versus midspam deflection patterns and failure modes.



(a) TX-1

(b) TX-2

Figure 10 - Stretching of the triaxial geogrid after reinforced-concrete beams failure.

4. CONCLUSIONS

This study revealed the feasibility of using geogrid reinforcements in PCC pavements. The experimental investigation was conducted to evaluate flexural behavior and post-cracking performance of reinforced and unreinforced concrete beams under four-point bending tests. Based on the results, load-vertical displacement curves showed that unreinforced concrete beams failed in a brittle mode immediately after peak, while reinforced-concrete specimens exhibited approximately up to 14% extra peak load and gained post-cracking ductility. Triaxial geogrids in concrete beams did not contributed mechanically in the pre-cracking phase, being the post cracking ductility and extra load capacity the main contributions. Results also showed that the presence of the triaxial geogrid provided an increase in flexural strength to the concrete beams by approximately 11%. Triaxial geogrid ribs were stretched after crack opening, illustrating the gradual rupture and crack delay behavior observed. Then, this study highlights the potential benefits of geogrids reinforcements in PCC pavements. Different types of test, geogrids type and position, concrete strength and load application are recommended.

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